a. Where shellfish are grown for human consumption, the median coliform densities should be 14 fecal coliform or 70 total coliform per 100 ml,

b. Where whole body contact of a receiving water is desired, the geometric mean over a 30-day period should not exceed 200 fecal coliform bacteria per 100 ml, with a maximum 7-day average of 400 per 100 ml,

c. Where secondary contact recreation is desired, such as boating, in-stream levels may be from 1,000 to 5,000 fecal coliform per 100 ml.

The predominant effluent criteria used in specifying performance requirements for UV systems at military facilities is that for whole body contact.

As a result of the concern associated with the dangers of chlorinated effluent and in particular the formation of trihalomethane (THM), many states have already enacted legislation limiting the amount of chlorine allowed in an effluent discharge. Limitations of 0.01 ppm require de chlorination ar an alternative method of disinfection such as UV.

2.6 Special Requirements

Several considerations should be included in the design and operation of a UV disinfection system. First, it must be simply designed and constructed, and must be provided with reliable equipment that is not labor intensive or complex in terms of maintainability, serviceability, and availability of parts. Second, the trend is toward limited operator manpower availability at Army treatment plants and this must be considered in the design. Third, operator safety must be incorporated in the design process.

3. FUNDAMENTALS OF ULTRAVIOLET DISINFECTION

3.1 Nature of Ultraviolet Light[34]

Ultraviolet light is invisible radiation within a range of the electromagnetic spectrum having a wavelength between 100 and 400 nanometers (nm). One nanometer unit wavelength equals 10 Angstroms, Å.

As can be seen in Figure 3-1, there are three main groups within the ultraviolet spectrum, only one of which the germicidal range of 200 to 280 nm is utilized for disinfection. The peak effectiveness for inactivation of micro-organisms occurs at the wavelength of 260 nm units, which is sometimes expressed as 2,600 Å. The relationship between bactericidal effect and wavelength is shown in Figure 3-2. Fortunately, this range coincides with the resonance line of mercury vapor lamps, 253.7 nm (Figure 3-3), the almost exclusively used sources of UV light for disinfection.

3.2 UV Light Disinfection Mechanics[34]

All microorganisms contain proteins and nucleic acid as their main components. Ultraviolet light disrupts these components and destroys the ability of microorganisms to reproduce, ie. they are inactivated and as a consequence can no longer cause disease.

The inactivation of microorganisms results primarily from the absorption of UV radiation by the deoxyribonucleic acid (DNA) of the organisms and subsequent dimerization of thymine bases in DNA.

In order to be effective, the electromagnetic waves of UV radiation must actually strike the microorganism. In the process, some of the radiation energy is absorbed by the organism and some by other constituents in the medium surrounding the organisms. The germicidal effect of UV energy is thought to be associated principally with its absorption by nucleic acids essential to the replication of cells. Energy dissipation by excitation, which causes disruption of the nucleic acid molecules that are vital to both bacteria and viruses, appears to produce a progressively lethal biochemical change. UV treatment does not chemically alter water since nothing is added except energy, which produces heat resulting in a negligible temperature rise in the treated wastewater.

3.3 UV Dose and Inactivation Time

The energy required to inactivate microorganisms varies with the particular species under attack. Radiation is typically expressed as a function of intensity (energy), time and area. Thus, UV dosages are expressed as microwatt seconds per square centimeter(μw-sec/cm^2).

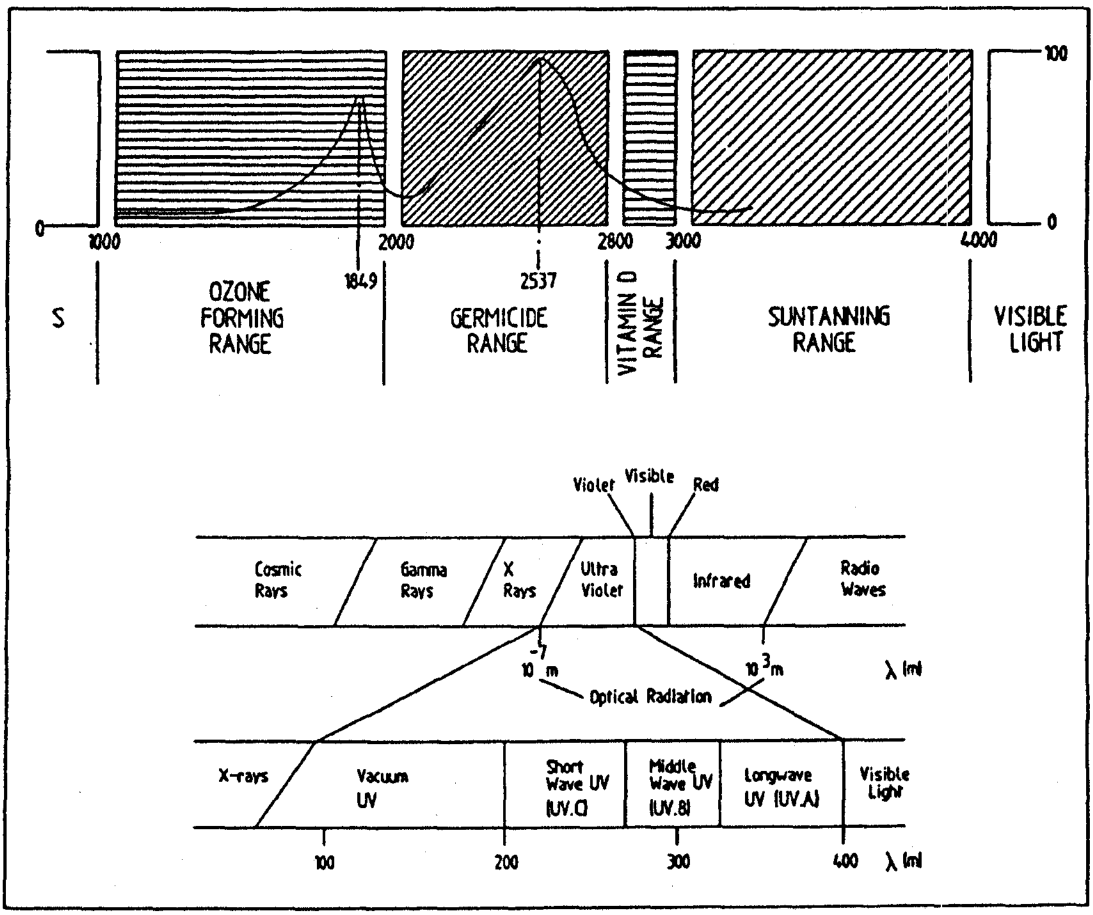

FIGURE 3-1 Electromagnetic spectrum with expanded scale of ultraviolet spectrum[34]

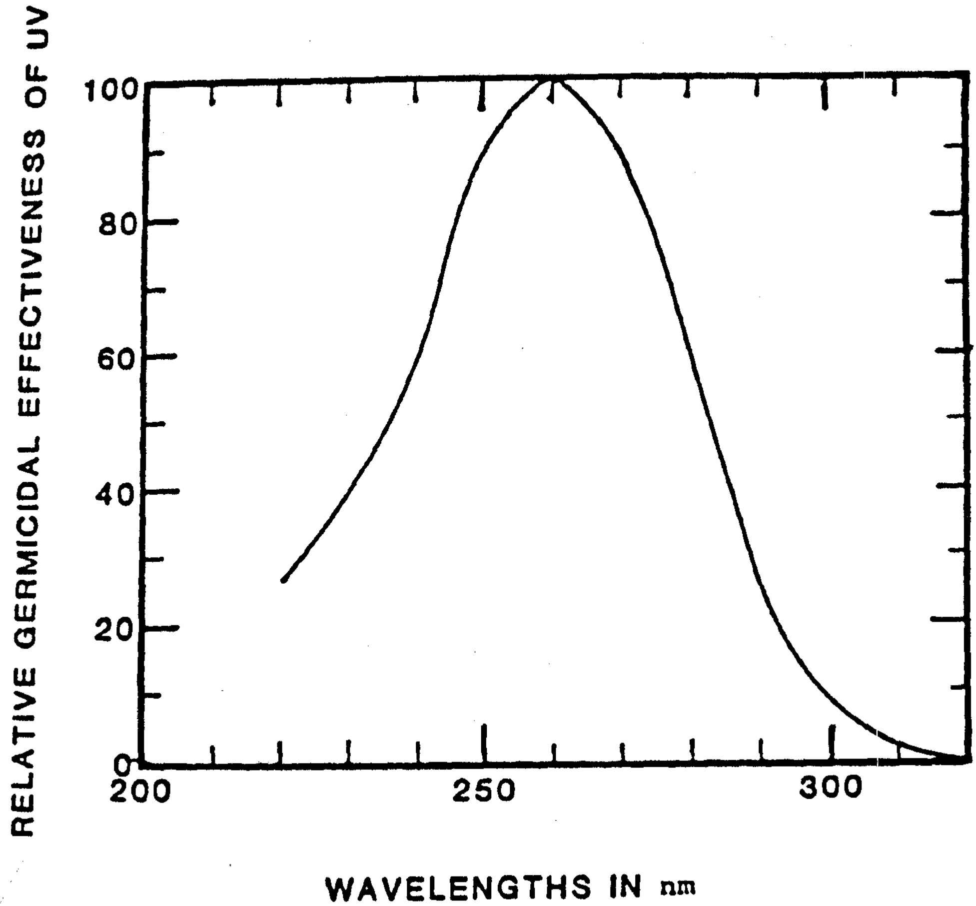

FIGURE 3-2 Relative bactericidal effectiveness of ultraviolet radiation[16]

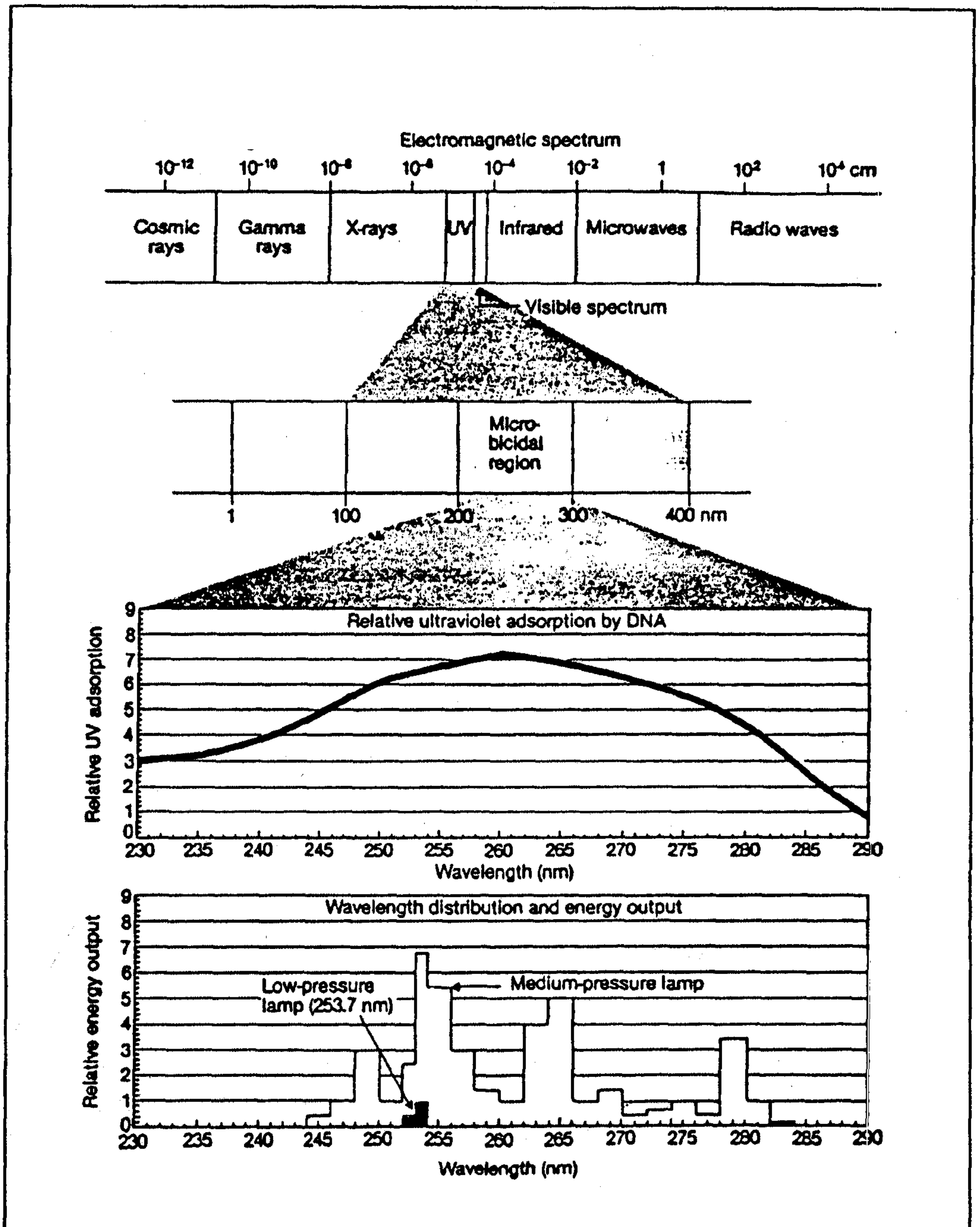

FIGURE 3-3 Microbiocidal wavelengths of UV and distribution of energy output for low and medium-pressure arc lamps[14]

The average UV light intensity, or the dose, has been measured indirectly by a bioassay technique which has been proven to be a reliable method of determining the UV dose necessary to destroy various organisms[33]. The laboratory procedure used is essentially as follows[34]:

1. A UV lamp is set up at a fixed distance from a petri dish (Figure 3-4).

2. A shield is placed over a portion of the UV lamp, and a collimating tube is positioned between the lamp and the petri dish.

3. A UV intensity meter is used to accurately measure the intensity of 253.7 nm at the point where the petri dish is located.

4. A pure strain of the microorganism to be evaluated is placed in the petri dish and mixed with a magnetic stirrer.

5. The experiment is repeated for various exposure times.

6. Each sample is then incubated, and the concentration (N_o) of the microorganisms before and after (N) exposure to UV light was determined.

7. The measured intensity multiplied by the specific exposure UV time represents the UV dosage.

8. The dose response curve is then plotted. It shows the log of the survival ratio N/N_o as a function of the UV dosage. Figure 3-5 gives an example. From Figure 3-5, the UV dosage for 90%, 99%, 99.9% etc. reduction respectively, 10%, 1%, 0.1% etc. survival ratio can be determined. If the necessary UV dosage for 90% reduction (10% survival) has the value X, it needs a UV dosage of 2X to obtain 99% reduction (1% survival), 3X for 99.9% (0.1% survival), 4X for 99.99% (0.01% survival) etc.

<u>For example</u>: If the intensity at the petri dish is 1,000 μw/cm², and the retention time for destruction of the organism is 5.6 seconds, the dosage to destroy the organism is 5,600 μw-sec/cm².

Using the collimated beam apparatus, the survival of a specific indicator organism is determined as a function of the UV dose under controlled laboratory conditions. The intensity can then be determined in an unknown system by determining the survival, reading the dose corresponding to the observed survival on the curve, an example of which is

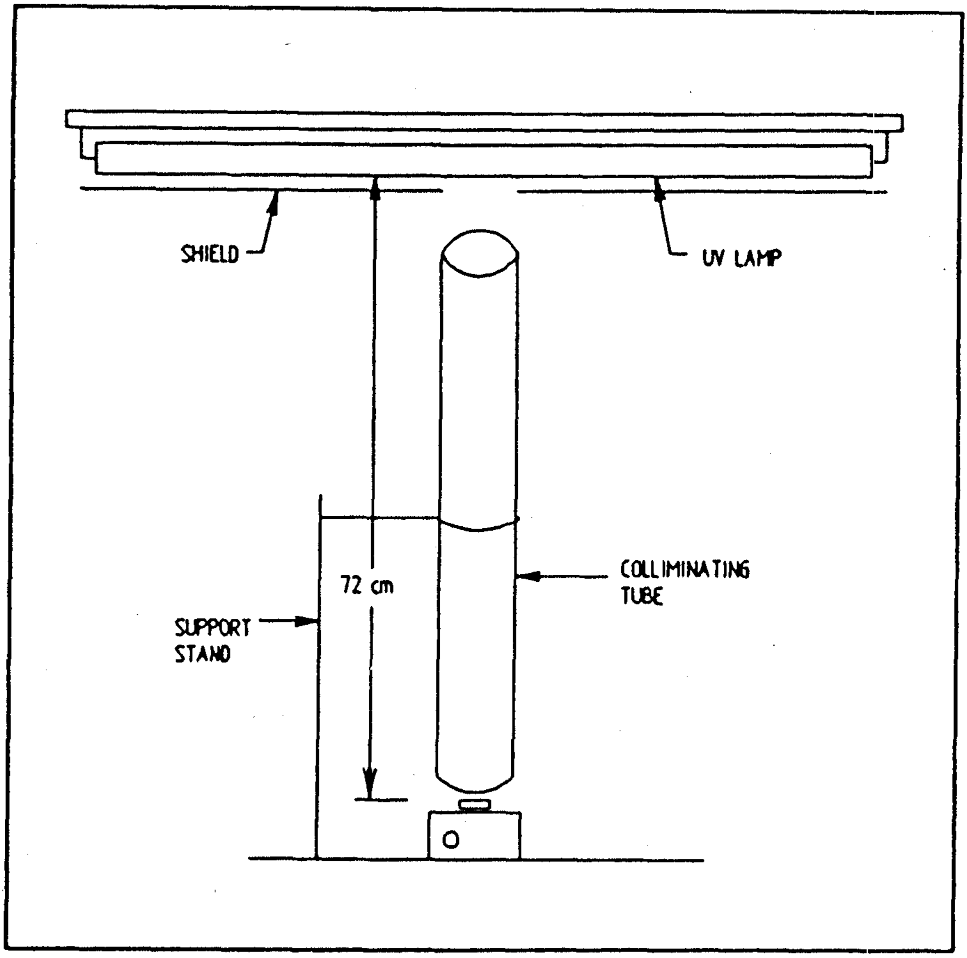

FIGURE 3-4 Collimated beam apparatus[34]

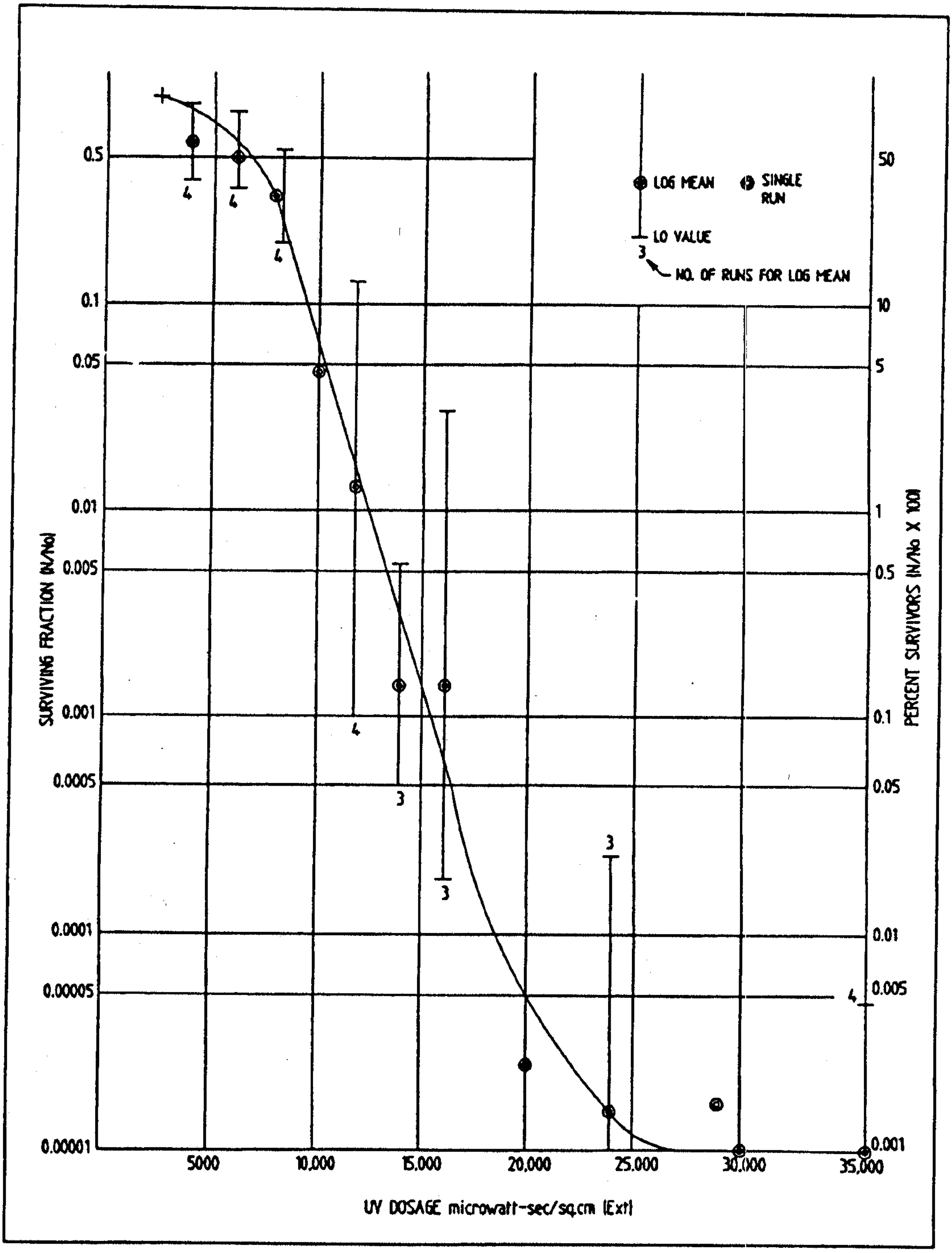

FIGURE 3-5 Dose-response reference curve[34]

shown in Figure 3-5, and using the known exposure to calculate average intensity.

3.4 E. Coli as Indicators[34]

There has been considerable discussion within the scientific community regarding the use of Escherichia Coli (E. Coli) as an indicator method. There are numerous organisms and viruses that survive standard chlorination. The absence of coliforms in a treated effluent does not indicate or guarantee the absence of these chlorine resistant organisms.

It is interesting to note that the same condition does not exist in the case of UV disinfection. Coliforms are among the most resistant of the waterborne organisms, and the absence of E. Coli in a UV treatment system is a good indication of the absence of the other significant microorganisms. Figure 3-6 shows this relationship.

UV light is a very powerful disinfectant. Comparison of doses required to inactivate various microorganisms applying different methods of disinfection is shown in Figure 3-6, where the required doses are related to a unity dose necessary to inhibit E. Coli. Figure 3-6 shows that one advantage of UV radiation over chlorine disinfection is the sensitivity of viruses to UV.

3.5 UV Disinfection Efficiency[34]

The disinfection efficiency of a UV system is primarily dependent on the UV dose. The required dose will vary as effluent quality varies. Determination of the actual dose being delivered involves defining the hydraulic detention time in the reactor throughout the expected range of flows, and defining the average intensity of the UV radiation in the reactor. These two parameters are reactor-specific. The average intensity to which the wastewater flow is exposed is a function of the total number of lamps, their types, size, and the geometry of the lamp placement in relation to the wastewater flow[15].

3.6 Factors Affecting UV Disinfection Efficiency

Because UV light must be absorbed into the microorganisms to achieve inactivation, anything that prevents the UV light from reacting with microorganisms will impair disinfection.

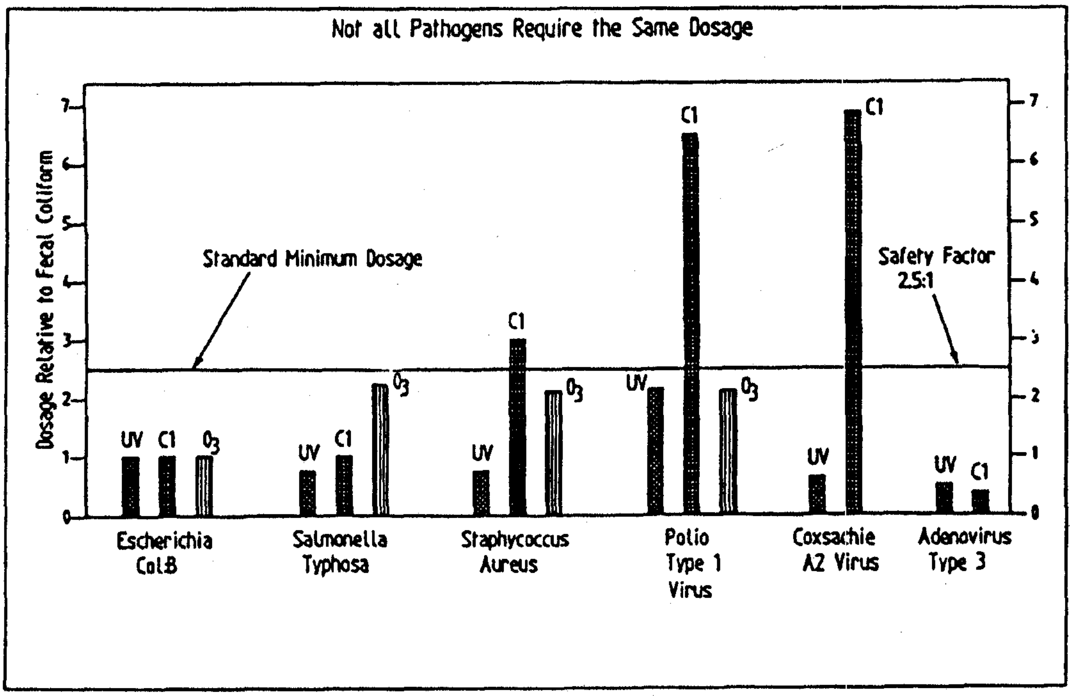

FIGURE 3-6 Comparison of relative dosages with UV, chlorine and ozone[34]

Conditions and materials that interfere with this process include chemical and biological films that develop on the surfaces of UV lamps; clumping or aggregation of micro-organisms, which has a protective effect; turbidity; color; dissolved organics and inorganics; and short-circuiting in water flowing through the exposure chamber. Disinfectant activity using UV, however, appears to be relatively independent of temperature and pH[14].

3.6.1 UV Transmittance at 254 nm

Ultraviolet light transmission through the fluid changes with the fluid density. The coefficient of absorption of the fluid is a very important factor to be considered in evaluation of UV dose. The coefficient of absorption of water or wastewater is not a constant and must be measured for each application.

Table 3-1 lists the typical UV light transmission levels for various fluids.

Table 3-1 Typical UV transmission levels
(Source: 19)

Fluid	Percent Transmission T_r	Coefficient of Absorption α (cm^{-1})
Distilled water	99	0.1
Potable water	80 - 90	0.2 - 0.1
Secondary effluent*	60 - 70	0.4 - 0.3
Liquid sugar	50 - 60	0.5 - 0.4

* Secondary effluent based on a survey of 200 random medium strength domestic secondary effluent.

The intensities of UV light reaching the irradiated bacteria change with the absorbance according to Equation 3.

In addition to the changes in ultraviolet transmission of the fluid, other factors that affect UV light intensity are:

1. depreciation of the output of the UV lamps with their age.

2. a formation of a coating on the quartz lamp jackets or fouling of the teflon tubes.

Power voltage drop also reduces lamp intensity and therefore ultraviolet disinfection efficiency.

3.6.2 Water and Wastewater Quality

To analyze the ultraviolet disinfection efficiency, several factors that affect the penetration of ultraviolet energy through water and, hence, the effective destruction of organisms should be considered[10]. Water and wastewater constituents may have a large impact on ultraviolet disinfection efficiency. The energy which kills a bacterium is only that absorbed by it, therefore, ultraviolet coefficients of absorption are affected by turbidity, iron salts and organic compounds in wastewater[20]. Compounds of calcium, magnesium, sodium, and aluminum have little effect on transmission, unless the compounds form a precipitate[20]. Water quality parameters such as temperature, pH, conductivity, alkalinity, total organic carbon (TOC), chemical oxygen demand (COD), total phosphorus, and ortho-phosphate, ammonia, nitrite, and nitrate affect wastewater transmittance, hence affecting ultraviolet reactor performance[10,21].

Where wastewater quality parameters do not show higher than the average for secondary effluent values, the impact of physical and chemical quality of wastewater on the overall UV disinfection efficiency is relatively low[10,22]. Huff, et al.[20], studied the effect of color on transmission and on limiting efficiency in destruction of organisms and determined that concentrations giving 30-33 units of color did not decrease intensities below the average values. Turbidities of 5 Jackson units did not reduce UV intensity and disinfection was sufficient to produce total and fecal coliform counts in the water within acceptable drinking water limits of <u>E</u>. <u>coli</u>. per 100 ml. while turbidities of 20 units sometimes reduced light intensities but the coliform counts were still within the limits of acceptance for potable water. The effect of iron on disinfection was not observed at concentrations up to 3.7 mg/1 as the UV transmittance of the solution decreased without resulting in a decrease in coliform removal. Other studies have concluded that water relatively low in turbidity, color, iron content, and organic composition could effectively be disinfected.

3.6.3 Temperature

Severin, et al.[10,23], concluded that the UV disinfection is relatively insensitive to temperature changes, since the calculated activation energies for three organisms studied were in the range of purely photochemical reactions[10].

3.6.4 Mixing

Mixing in the radial direction of an annular reactor was found to be beneficial while mixing in longitudinal direction is detrimental to reactor efficiency[10, 24].

3.6.5 Suspended Solids

The presence of particulate materials in wastewater also affects ultraviolet disinfection. Absorption of microorganisms to inorganic surfaces provides some protection against radiation. Organic particles can significantly protect organisms from disinfection and the difference between microbial survival in irradiated raw wastewater and secondary effluent has been attributed to differences in particle sizes. Bacteria inside aggregates of particulate matter are partially protected from ultraviolet light. Secondary wastewater effluent subjected to mixed media filtration and exposed to UV at different flow rates, and different lamp intensity rates showed significantly better disinfection than unfiltered effluent[10].

3.6.6 By-Products of UV Radiation

Undesirable disinfection by-products (DBP's) in water and wastewater are classified into two general categories -those which are harmful to health and to fish and those which affect the water's aesthetic quality. The literature indicates that UV disinfection does not contribute to either by-product category. UV radiation does not produce increased mutagenic activity in water, does not produce assimilable organic carbon (AOC), and produces no tastes and odors or other measurable water quality by-products[14].

4. ULTRAVIOLET DISINFECTION SYSTEM DESIGN

4.1 Salient Features of UV Systems

The following are essential elements of UV systems that should be included in the design and specifications.